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Population densities of yellow starthistle (*Centaurea solstitialis*) in Turkey

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Yellow starthistle is one of the most important alien invasive weeds in the western United States. It has been targeted for biological control based on the assumption that its abundance is limited by natural enemies in its native region but not in the United States. The geographic center of diversity for yellow starthistle appears to be in Turkey. This region is being explored to discover potential biological control agents; however, there is no quantitative information regarding the population density or dynamics of the plant in this region. Such information could help determine which natural enemies help suppress the plant in its land of origin. We measured densities of yellow starthistle plants and seeds during 2 yr at three locations in central Turkey. Densities of mature plants were about 4% of those measured at sites in California. Densities of capitula and seeds produced were about 60 and 65%, respectively, of those measured in California. The greatest difference between the two regions appears to be the densities of mature plants, which indicates the importance of focusing research on natural enemies that reduce plant survival.

Nomenclature: Yellow starthistle, *Centaurea solstitialis* L. CENSO.

Key words: Biological control, invasive species, plant density, Asteraceae, thistle.

Yellow starthistle is an important invasive rangeland weed in the western United States that is continuing to spread (Duncan 2001; Maddox et al. 1985). It is designated as noxious in 11 western states and two Canadian provinces (Skinner et al. 2000). Yellow starthistle originates from the Mediterranean region and has been targeted for biological control (Maddox 1981; Rosenthal et al. 1992; Sheley et al. 1999; Turner et al. 1995). Six insects that attack capitula have been approved and introduced into the United States from Greece and Italy (Rees et al. 1996; Turner et al. 1995), and a seventh species was accidentally introduced (Balciunas and Villegas 2001). Although most of these agents are established, they do not provide effective control in California (Pitcairn et al. 1998, 2000a), where most of the infested land occurs (Duncan 2001).

The genus *Centaura* contains 530 to 550 species and is distributed from Spain across southern Europe to Turkey and Iran (Klokov et al. 1963). The genus is taxonomically difficult, and its phylogenetic relationships remain unresolved (Susanna et al. 1995). *Centaurea solstitialis* was placed in the section *Mesocentron* by Wagenitz (1975) and in the subgenus *Solstitiaria* by Dostál (1976). Six subspecies of *Centaurea solstitialis* have been described, four are found in Europe (Dostál 1976) and three in Turkey (Wagenitz 1975). *Centaurea solstitialis* ssp. *solstitialis* L. occurs throughout most of the species range (Dostál 1976). The other subspecies have restricted distributions, but more subspecies occur in or near Turkey than in any other region. Thus, Turkey is considered to be a promising region for discovering candidate biological control agents to introduce into the United States. Previous explorations have concentrated on western Europe from Spain to Greece (Clement 1990; Clement and Sobhian 1991; Sobhian and Zwölfer 1985). Exploration of Turkey began later (Rosenthal et al. 1994), and evaluation of natural enemies from Turkey is only just beginning (Smith 2002).

Yellow starthistle in the western United States is genetically diverse (Sun 1997) and likely consists of a mixture of various subspecies of *Centaurea solstitialis.* Some plants that are more or less referable to subspecies *schouwii* and *erythracantha* have been collected in California, but most specimens do not match any of the recognized intraspecific taxa (F. Hrusa, personal communication).

Classical biological control is considered to most likely succeed if there are host-specific natural enemies in the land of origin that do not occur in the adventive regions, where the plant is invasive (Harley and Forno 1992; Huffaker et al. 1976). In the case of yellow starthistle, insects and pathogens already present in California are generally thought to cause insufficient damage to reduce the plant population (Johnson et al. 1992; Pitcairn et al. 1999). However, yellow starthistle population densities have decreased at some sites in Oregon and Idaho in the presence of high densities of some of the agents (E. Coombs, personal communication;

T. Prather, personal communication), which suggests that these agents may have some effect in some habitats. Although pathogens, such as *Colletotrichum gloeosporioides* (Penz.) Penz. & Sacc. and *Sclerotina minor* Jagger, and slugs have been observed to kill large numbers of seedlings, this occurrence appears to be sporadic and somewhat localized (Pitcairn et al. 2000b). However, it is possible that yellow starthistle populations in the land of origin are not limited by host-specific natural enemies. Thus, it is important to not only look for potential new agents but also to determine if and why yellow starthistle is less abundant in Turkey than it is in regions of the United States with similar climates. Understanding what regulates the population in the land of origin may help us discover ways to help control the plant in the United States.

Yellow starthistle occurs throughout Turkey and is found primarily in pastures, along field margins and roadsides, and in wheat (*Triticum aestivum* L.) fields (Kurcman 1993; Uygun et al. 1996; Uygur 1997). It occurs from sea level to about a 1,900-m elevation in the Mediterranean and Central Anatolian climatic regions. The plant tends to occur in ruderal patches that were generally small and often many kilometers apart. This distribution pattern differs dramatically from the continuous dense infestations of roadsides and grasslands in many parts of California and nearby states.

The purpose of this article is to review what is known about yellow starthistle in Turkey and to compare its density and population dynamics in Turkey with those in California, where it is a highly invasive weed.

Materials and Methods

Study Sites

Observations were made in 1999 and 2000 at three locations in Turkey that represented different edaphoclimatic regions: Mediterranean, Central Anatolian with stony clay soil, and Central Anatolian with sandy soil. All locations were at uncultivated sites along roadsides. There were no signs of vegetation management at any of the sites; however, they were exposed to occasional grazing by small flocks of sheep or goats. Each location was 72 to 78 km from the others.

Location 1

Catalan (latitude 37°05′21.6″N, longitude 35°22′53.5″E, elevation 198 m), near Adana, represents Turkey's Mediterranean climate. It is characterized by hot dry summers and mild rainy winters; mean annual precipitation is 584 mm. The site was a 5- by 30-m area between a paved road and a wheat field. The soil was stony clay, and the location was occupied by *Centaura solstitialis carneola* (pink-flowered subspecies of yellow starthistle), which is endemic to this region of Turkey. Other species included Syrian mesquite [*Prosopis farcta* (Banks & Sol. in Russ.) Ma], johnsongrass [*Sorghum halepense* (L.) Pers.], and bermudagrass [*Cynodon dactylon* (L.) Pers.].

Location 2

Camardi (latitude 37°43′36.2″N, longitude 35°01′13.1″E, elevation 1,460 m), near Nigde, represents Turkey's Central Anatolian climatic region. It has a mild summer and cold rainy winter; mean annual precipitation is 310 mm. The site was a 20- by 30-m area of rocky debris left over from road construction. The soil was stony clay and supported a population of *Centaura solstitialis solstitialis*. Other common plant species included some weedy herbaceous species, including *Astragalus* spp.

Location 3

Goreme (latitude 37°39′44.2″N, longitude 35°49′55.8″E, elevation 1,160 m), near Nevsehir, also represents the Central Anatolian climatic region, but the site was drier because the soil has more sand and volcanic tufa. Mean annual precipitation is 384 mm. The site was a 3- by 15-m area beside the road and was occupied by *Centaura solstitialis solstitialis*. Other common species included Russian knapweed [*Acroptilon repens* (L.) DC.] and some weedy grass species, including bermudagrass.

Comparable data were collected by California Department of Food and Agriculture scientists at three sites in Placer, Yolo, and Sonoma counties in California (Pitcairn et al. 2002). The Yolo site was in open Sacramento Valley rangeland located west of Woodland (latitude 38°40′43″N, longitude 121°46′20″W, elevation 20 m) with silty clay soil; common plants included rose clover (*Trifolium hirtum* All.), soft brome [*Bromus hordeaceus* L. ssp. *molliformis* (Lloyd) Maire & Weiller], California burclover (*Medicago polymorpha* L.), common vetch (*Vicia sativa* L.), and reddish tufted vetch (*Vicia benghalensis* L.) (D. Woods, personal communication).

The Placer site was in the Sierra Nevada foothills east of Auburn (latitude 38°53′48″N, longitude 121°04′33″W, elevation 396 m) surrounded by a mixed conifer–oak woodland with sandy loam soil; common plants included soft brome, suckling clover (*Trifolium dubium* Sibth.), rose clover, narrowleaf plantain (*Plantago lanceolata* L.), and hogbite (*Chondrilla juncea* L.).

The Sonoma site was in the Coast Range foothills southeast of Santa Rosa (latitude 38°26′26″N, longitude 122°42′48″W, elevation 366 m) surrounded by oak woodland with clay loam soil; common plants included soft brome, Carolina geranium (*Geranium carolinianum* L.), *Elymus* spp., rattail fescue [*Vulpia myuros* (L.) K.C. Gmel.], bedstraw (*Galium* spp.), spreading hedgeparsley [*Torilis arvensis* (Huds.) Link], and cutleaf geranium (*Geranium dissectum* L.).

Climatic data recorded at meteorological stations closest to the three Turkish field locations were used to represent the weather during the course of the studies. The Catalan, Camardi, and Goreme sites were about 15, 10, and 10 km from their respective meteorological stations (stations 17351, 17906, and 17835) operated by the Turkish State Meteorological Service. Climatic data to represent the California sites were obtained from the University of California Statewide Integrated Pest Management Program (http://www.ipm.ucdavis.edu, weather station: Sacramento FAA Airport, years: 1961–1990). Annual thermal accumulations, from January through September, were estimated based on monthly mean temperature data, using 2 C as the developmental threshold for yellow starthistle (Monteith 1981; Roché et al. 1997). Although this does not provide a very precise measure of degree day accumulation, it is adequate for comparing the different study sites.

Seed Bank and Plant Density

At each of the three study sites, 20 square frames (0.25 by 0.25 m) were randomly placed on the ground. Four soil cores (2 cm in diameter, 16 cm deep) were collected, one in the center of each quadrant of the frame, and combined to make one 200-cm^3 sample representing each frame. Soil samples were separated by washing with tap water for 10 min in a series of sieves (630-μm and 1-, 2-, and 2.5-mm aperture). Yellow starthistle seeds in the bottom two sieves were visually identified and counted. Seeds were identified based on comparison with known specimens, and no other *Centaurea* species were observed at the sites, which could cause confusion. Seed counts were converted to seeds per square meter by multiplying by 10,000/(4 × 3.14). Samples were taken at Catalan on June 16, 1999, and June 7, 2000, and at Camardi and Goreme on July 3, 1999, and June 27, 2000, to measure the minimum seed density at the end of the germination period. Samples for maximum seed density were taken at the end of the growing season: on November 11, 1999, and November 8, 2000, at Catalan and on December 14, 1999, and November 15, 2000, at Camardi and Goreme. The actual time of seed germination has not been studied in Turkey, and it was hoped that these dates would precede the major germination period.

Density of yellow starthistle rosettes was measured on May 15 to 17, 2000, using 20 randomly placed frames (0.5 by 0.5 m) at each site. Density of mature plants and capitula were measured when the plants had stopped flowering using 10 randomly placed frames (0.5 by 0.5 m) at each site: at Camardi and Goreme on July 27, 1999, and August 10, 2000, and at Catalan on August 17, 1999, and August 2, 2000. The number of capitula on all plants that were rooted inside the frame was determined.

Statistical Analysis

Analysis of variance (ANOVA) and general linear models (GLM) were performed using SuperANOVA[1] on count data that were transformed by square root of (Y + 0.5). Fisher's Protected LSD, using alpha = 0.05, was used to make post hoc multiple comparisons. Reported means and standard errors (SE) were back transformed. Nonlinear regression was performed on Statistica[2] using the quasi-Newton estimation method.

Results and Discussion

Climate

Sacramento, CA, located in the Central Valley, is representative of the Mediterranean climatic region in the United States where yellow starthistle is most abundant (Figure 1). All the Turkey locations had a 3-mo summer dry season, although usually not as dry as that in Sacramento. The summer dry season also started later in the year (July) at Camardi and Goreme than at Catalan or Sacramento (June). Precipitation at Sacramento (445 ± 30 [SE] mm) was more than that at the two Central Anatolian sites, Camardi (310 ± 13 mm) and Goreme (384 ± 33 mm), but less than that

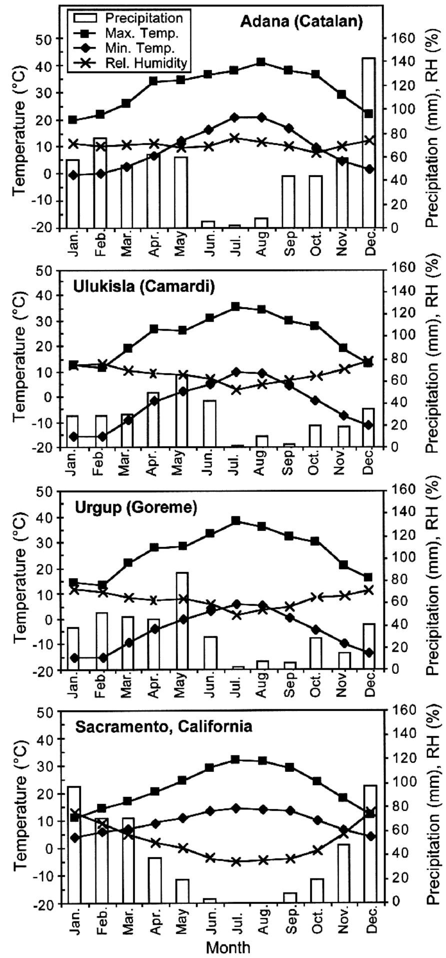

FIGURE 1. Mean climatic conditions near three field locations in Turkey, Adana station near Catalan site, Ulukisla station near Camardi, and Urgup station near Goreme, and at Sacramento, California.

at Catalan (584 ± 60 mm; September to August for 3 yr: 1998–2001). The Catalan site had the warmest climate (5,300 degree days, based on mean monthly temperatures greater than a 2 C threshold during four calendar years: 1998–2001). Annual accumulated degree days at Camardi (2,960) and Goreme (3,220) were less that at Sacramento (4,170). A minimum of 2,100 degree days is needed for yellow starthistle to reach 50% seed maturation (Roché et al. 1997), so all sites were suitably warm. However, winter temperatures at Camardi and Goreme were much lower than those at Sacramento (Figure 1). Subfreezing winter temperatures may increase mortality of yellow starthistle plants that germinate in the fall (Sheley and Larson 1994). Thus, spring germination may be more important to plant recruitment in Central Anatolia than in central California.

Weather data from the three sites in Turkey recorded during the course of the experiment are presented in Figure 2. Precipitation available to yellow starthistle on an annual basis was considered to be that accumulated from September to August for Catalan and from October to September for Camardi and Goreme based on the usual ending of the summer dry season (Figure 1). Annual precipitation at Catalan was 700 mm in 1999 (September 1998 to August 1999) and 505 mm in 2000. Precipitation at Camardi was 341 and 296 mm and at Goreme was 439 and 395 mm, in 1999 and 2000, respectively. Precipitation decreased at

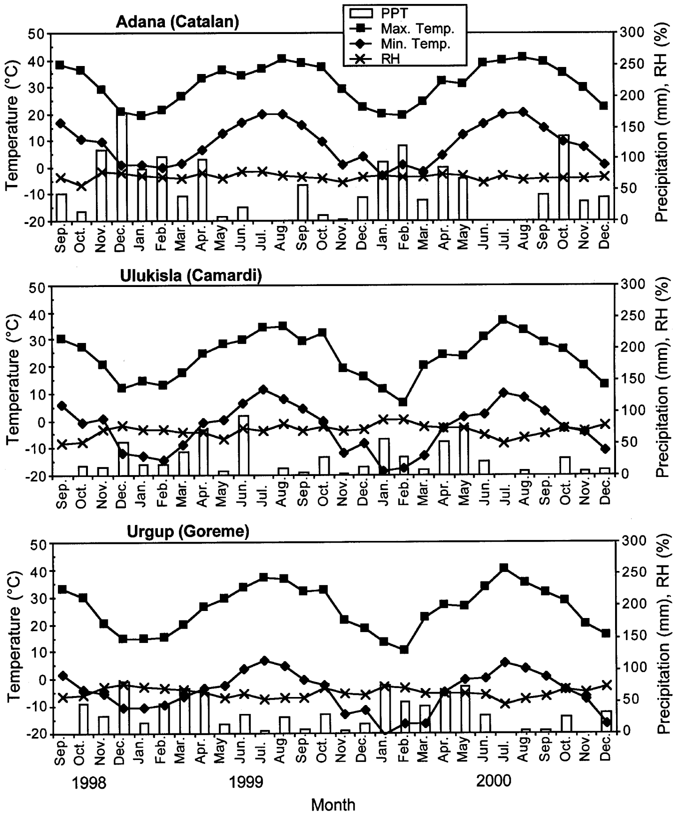

FIGURE 2. Climatic conditions during the study (1998–2000) near field locations Catalan (Adana station), Camardi (Ulukisla station), and Goreme (Urgup station).

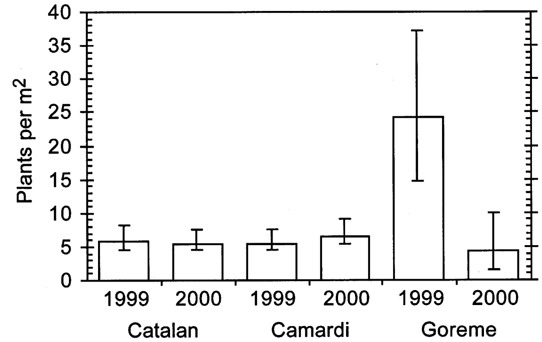

FIGURE 3. Densities of mature yellow starthistle plants at three locations in Turkey (mean ± 95% confidence interval; two-way analysis of variance, year: $P < 0.0007$, location: $P = 0.0004$, interaction: $P = 0.0001$).

all locations between 1999 and 2000 by 28, 13, and 10% at Catalan, Camardi, and Goreme, respectively.

Mature Plants and Capitula

Densities of mature yellow starthistle plants generally did not differ between the 2 yr or between the three sites in Turkey except that the population was much higher at Goreme in 1999 (Figure 3). There is no obvious climatic explanation for this anomaly, but it is possible that the increase in population was caused by a disturbance to the site that occurred before the observation period. Yellow starthistle is a ruderal plant in this region, and soil disturbance may be the most likely cause of a temporary increase in the plant population. The decline of the plant population at this site to a level comparable with the other sites supports the hypothesis that high population densities are very ephemeral in this region.

Capitula densities were generally lower in 2000 than in 1999 (Figure 4). The densities at the three sites were not significantly different in 1999, but in 2000 each of the three sites differed. The greatest decrease in capitula density occurred at Goreme, where plant density also decreased dramatically (Figure 3). However, the plant density at Goreme in 2000 was similar to those at the other two sites, so some other factor also contributed to the reduction of capitula production at this site. Precipitation decreased at all the locations from 1999 to 2000 (Catalan, 700 to 505 mm; Camardi, 341 to 296 mm; Goreme, 439 to 395 mm). However, the smallest decrease in precipitation (10%) occurred at Goreme, where capitula density decreased the most, and precipitation decreased the most (28%) at Catalan, where capitula density decreased the least. Precipitation was significantly related to capitula density ($P = 0.006$), but precipitation explained less of the variance than did year ($P = 0.0001$). Thus, it appears likely that other biotic factors, such as natural enemies or competitors, may have been more important causes of the decrease in reproductive output of yellow starthistle between years. Such a decline is consistent with the theory that yellow starthistle may be able to rapidly exploit a disturbed site but that its natural enemies then increase over time and cause the isolated population to decline. However, no data were collected regarding the possible role of natural enemies in the decline of capitula densities.

The number of capitula per plant decreased from 1999 to 2000 at all locations (Figure 5). The number was lowest at Goreme, the most xeric site, and highest at Catalan, the warmest and most mesic site. This pattern is similar to that of capitula per square meter (Figure 4) and is probably related to decreased precipitation and perhaps increases in natural enemies or competitors.

At Goreme, in 1999, where plant densities were unusually high, there was a significant relationship between the number of capitula per plant and plant density (Figure 6; nonlinear regression, $Y = 145\ [\pm 21\ \mathrm{SE}] \times X^{(-1.11\ [\pm 0.13])}$, $R = 0.67$). However, in 2000, the number of capitula per plant was extremely low at all plant densities (linear regression was not significant, $P = 0.29$, mean $= 2.2 \pm 0.6$). A similar pattern occurred at Camardi, although the plant densities were too low to show very much of the functional

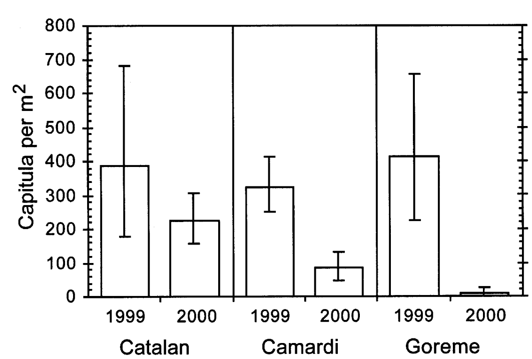

FIGURE 4. Densities of yellow starthistle capitula at three locations in Turkey (mean ± 95% confidence interval; two-way analysis of variance, year: $P = 0.0001$, location: $P = 0.005$, interaction: $P = 0.002$).

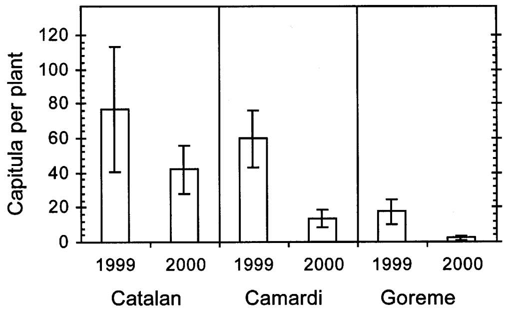

FIGURE 5. Numbers of capitula per plant at three locations in Turkey (mean ± 95% confidence interval; two-way analysis of variance, year: P = 0.0001, location: P = 0.0001, interaction: P = 0.10).

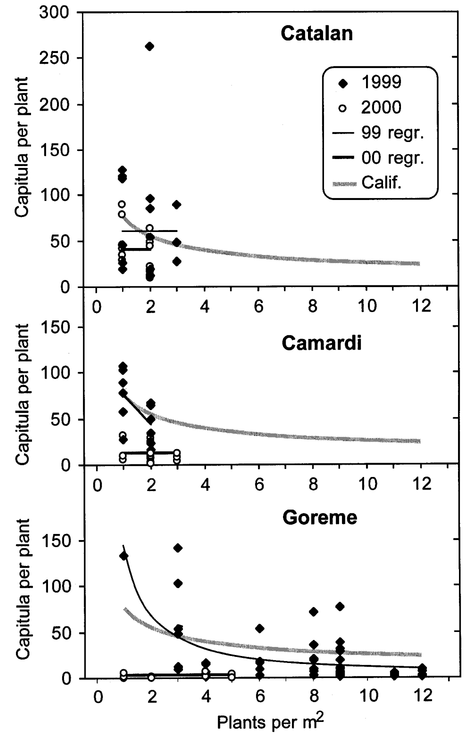

FIGURE 6. Relationship of reproductive potential of individual yellow starthistle plants to plant density at three locations in Turkey. Regression curve for California is from Pitcairn et al. (1997). See text for details.

relationship (in 1999, $Y = -31.0$ [± 13.1 SE] $\times X + 108$ [± 21.6], P = 0.036; in 2000, linear regression was not significant, P = 0.15, mean = 13.6 ± 2.5). At Catalan, there was no relationship of capitula per plant to plant density in either year (in 1999, P = 0.75, mean = 76.7 ± 16.9; in 2000, P = 0.15, mean = 41.9 ± 6.4). The data from Catalan in 1999 and 2000 and those from Camardi in 1999 fall close to the regression curve fit to the data from Goreme in 1999. In other words, plants at densities of 1 to 3 plants m^{-2} produced about 50 to 120 capitula in an inverse density-dependent relationship. However, at Goreme and Camardi in 2000, this relationship changed, and the plants produced fewer capitula than predicted by plant density. The cause of such a drastic reproductive debilitation of the plants is unknown.

Much of our data on the number of capitula per plant are similar to those observed in California during a field experiment conducted near Davis in 1995 (Figure 6; Pitcairn et al. 1997; $Y = 76.46X^{(-0.481)}$). Although most of the California data were collected at much higher densities of yellow starthistle (4 to 400 plants m^{-2}) than that observed in Turkey, their regression curve falls well in the range of our data for both years at Catalan and for 1999 at Camardi and Goreme. The very low numbers of capitula observed in 2000 at Camardi and Goreme differ dramatically from the California data.

Rosette densities in 2000 were significantly greater at Camardi (14.3 ± 0.1) than at Catalan (5.45 ± 0.06) or Goreme (8.33 ± 0.06) (P = 0.0019). Comparison of rosette with mature plant densities in 2000 is an indication of summer mortality. The plant densities decreased more at Camardi (54%, from 14.3 to 6.6 plants m^{-2}) and Goreme (47%, from 8.3 to 4.4 plants m^{-2}) than at Catalan (0%, from 5.4 to 5.4 plants m^{-2}). There was more grazing by sheep and goats at Camardi than at the other locations, which could partially explain the higher mortality of rosette plants. Perhaps the rosette density of 14.3 plants m^{-2} (or even 8.3 plants m^{-2}) was too high for the environment to sustain because mature plant densities at all the sites in 2000 were only 5.6 to 6.8 plants m^{-2} (Figure 3).

Soil Seed Bank

The season when yellow starthistle germinates in Turkey is not well known and was not an objective of our study. However, information collected in the United States can help us predict when it is likely to occur. Enloe and DiTomaso (2001) showed that only 15 to 20% of the yellow starthistle seed bank germinated in response to 4 cm of precipitation in September at two sites in California, whereas 45 to 65% germinated after the first sustained rains in October. Application of 2.5 cm of water was not sufficient to stimulate germination of yellow starthistle seed in September in California. The germination rate of fresh seeds decreases at soil temperatures greater than a constant 20 C or a diurnally fluctuating 25/15 C (Joley et al. 1997). At our sites in Turkey, high temperature inhibition probably prevented most seeds from germinating in response to precipitation events in September, and events with less than 2.5 cm were probably insufficient to produce the −1 MPa osmotic potential needed to stimulate germination (Enloe and DiTomaso 2001; Larson and Kiemnec 1997). Based on the observed weather patterns (Figure 2), the November and December sample dates for the seed bank generally do not appear to be too late to precede the major period of germination. However, winter rains started up to 2 mo before the fall 2000 sample date at Catalan. This may have resulted in germination of many seeds, which would have caused us to underestimate the maximum soil seed bank density at Catalan in the fall of 2000. In future studies, fall samples should be collected in early September to be more certain to precede germination events.

The density of seeds in the soil was generally higher in the fall than in early summer (Figure 7; three-way ANOVA; season, P = 0.0001; site, P = 0.0001; year, P = 0.0001). The decrease in seed densities from the fall to the next summer represents germination or destruction of seeds during the winter rainy season (Figure 1). The decreases in seed bank densities from the fall of 1999 to the summer of 2000 were 73, 90, and 84% at Catalan, Camardi, and Goreme, respectively. Seed density was higher in the fall of 1999 than

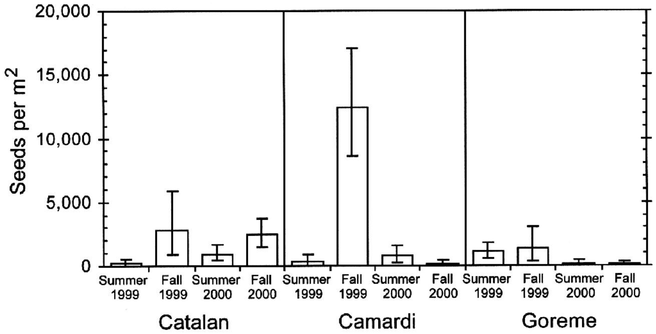

FIGURE 7. Densities of yellow starthistle seeds in the soil at three locations in Turkey (mean ± 95% confidence interval).

in the fall of 2000 (two-way ANOVA; year, $P = 0.0001$; location, $P = 0.0001$), reflecting the differences in capitula densities (Figure 4). In general, fall seed densities were correlated to capitula densities during the preceding summer (Pearson's $R = 0.76$, $P < 0.05$). Overall, there was no significant difference in the summer seed bank densities between the 2 yr, suggesting that attrition, whether through mortality or germination, must occur at much higher rates when the fall seed bank is high. It would be interesting to discover what factors are causing this density-dependent reduction because they may play an important role in the regulation of the plant's population.

Comparison with California Populations

Fall (maximum) soil seed densities at the three sites in Turkey (mean 4,291 seeds m^{-2}; range 358 to 14,045 seeds m^{-2}) were about 65% of seed production estimates observed at three sites in California studied for 7 yr (mean 6,556 seeds m^{-2}; range 506 to 27,163 seeds m^{-2}) (Pitcairn et al. 2002). Heavily infested sites in California produce 12,000 to 49,000 seeds m^{-2} (DiTomaso and Gerlach 2000). The density of mature plants at the sites in Turkey (mean 9.4 plants m^{-2}; range 5.6 to 26.4 plants m^{-2}) was about 4% of that at sites in California (mean 225 plants m^{-2}; range 28 to 975 plants m^{-2}). The density of capitula at the sites in Turkey (mean 266 capitula m^{-2}; range 15 to 460 capitula m^{-2}) was about 60% of that at sites in California (mean 225 capitula m^{-2}; range 28 to 975 capitula m^{-2}) (Pitcairn et al. 2002). Summer (minimum) soil seed densities (mean 1,048 seeds m^{-2}; range 438 to 1,472 seeds m^{-2}) were about 26% of those observed during 3 yr in California (mean 3,830 seeds m^{-2}; range 1,804 to 7,463 seeds m^{-2}; Joley et al. 2003). Thus, the greatest difference between the two regions was the much lower density of adult plants in Turkey. Discovering the causes of this mortality may help researchers find effective new biological control agents to use in the United States.

Possible Role of Natural Enemies

In 1999 at Goreme, some yellow starthistle plants were severely stunted, apparently due to infection by a phytoplasma-like organism. Damage caused by such natural enemies may help explain why, despite higher densities of adult plants and capitula, the subsequent fall soil seed densities were lower than those at the other two locations. The relatively low density of seeds in the soil at Goreme in the fall of 1999 may help explain the subsequent decrease in plant densities in 2000. The very high seed density at Camardi in the fall of 1999 was followed by high rosette densities the next June, but by August the plant densities had fallen to levels similar to the other two sites. This suggests that there are factors acting on dense populations that reduce them to low levels. Plants showing signs typical of eriophyid mite damage were found at both Camardi and Goreme in 2000 (de Lillo et al. 2003). The weevil *Ceratapion basicorne* (Illiger), which develops in root crowns, infested 100% of the plants at Catalan and Camardi and 50% at Goreme in 1999. In 2000, weevil infestation rates decreased at Catalan (to 30% of plants), remained about the same at Camardi (80%), and increased at Goreme (80%) (S. Uygur, unpublished data). No data were collected on capitula insects, although three species of weevils [*Bangasternus orientalis* (Capiomont) at Catalan and Goreme, *Eustenopus villosus* (Boheman) at Camardi and Goreme, and *Larinus curtus* Hochhut at Catalan] were collected during the study. The stem-boring weevil (*Lixus scolopax* Boheman) was collected at Goreme. Roadside grazing by goats and sheep is common in this region of Turkey and probably affects the plant. However, without quantitative data, it is impossible to know the direct effect of these natural enemies on plant densities or seed production. Detailed quantitative studies should be conducted in Turkey to provide a basis for comparing the effect being obtained at locations in the western United States. Obtaining more detailed information on seasonal changes in densities of immature plants and stage-specific survival of plants in the two regions would help indicate which plant stages suffer high mortality. This would help indicate whether additional capitula insects are needed or whether agents that attack vegetative parts of the plant would be more likely to provide effective control.

Conclusions

Densities of mature yellow starthistle plants were about 4% of that observed at three sites in California. The unusually high density of 26 plants m^{-2} observed at Goreme in 1999 was still below the range of densities that have been observed at infested sites in California. The relatively small (65%) difference between fall soil seed densities in Turkey and seed production in California suggests that the level of seed production is not an important difference between the two regions. Therefore, differences in mortality of seeds, seedlings, or rosettes must account for the large difference in the observed densities of mature plants. The study of how much biotic factors, such as pathogens, insect, and vertebrate herbivores, and plant competition limit the survival of seeds and immature plants should help indicate which natural enemies may be most effective to help reduce populations of the weed in California.

Sources of Materials

[1] SuperANOVA, version 1.11, Abacus Concepts, Inc., 1984 Bonita Avenue, Berkeley, CA 94704.

[2] Statistica, version 5.1, Statsoft, Inc., 2300 East 14th Street, Tulsa, OK 74104.

Acknowledgments

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